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Perers, Bengt; Furbo, Simon; Fan, Jianhua; Kong, Weiqiang; Chen, Ziqian

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Drain Back, Low Flow Solar Combi Systems. Design, Monitoring and Simulation

B. Perers, S. Furbo, J. Fan, W. Kong, Z. Chen.

DTU Civil Engineering, Technical University of Denmark. Brovej, Building 118. DK-2800 Kgs. Lyngby. beper@byg.dtu.dk

Summary

Drain Back systems with ETC collectors are tested and analyzed in a Danish - Chinese cooperation project. Experiences from early work at DTU, with drain back, low flow systems, was used to design two systems:

1) One laboratory system at DTU and 2) One demonstration system in a single family house in Sorö Denmark. Detailed monitoring and modelling of the system in the DTU lab is done to be able to generalize the results, to other climates and loads and to make design optimizations.

The advantage with drain back, low flow systems, is that the system can be made more simple with less components and that the performance can be enhanced. A combination of the drain back- and system expansion vessel was tested successfully. Small initial problems with installation and proposals for design improvements to avoid these in practice are described in the paper. Installer education and training is an important step to have success with drain back systems.

Key-words: Drain Back, Low Flow, Solar Combi System, ETC collectors.

1. Introduction

This paper gives a status from an ongoing Danish – Chinese cooperation project with the aim to improve and promote drain back solar combi systems. Drain back systems have been tried and used for a very long period. Even the first MIT solar house from 1939 did apply drain back [14]. One of the first scientific publications is from 1981. This ISES paper demonstrates the advantages of drain back systems by both simulation and experiments at CSU. Also economic advantages are stated [11]. The drain back system type has been very successful on some special markets, like in the Netherlands, due to special restrictions for antifreeze solutions in solar collector loops heating domestic hot water [2]. Also low flow in the collector loop applied here is well known and studied in detail at DTU in combination with drain back [1, 3]. An overview on the low flow principle is given in [13]. The early work at DTU showed that all barriers for safe operation of drain back systems, can be overcome if the system is properly designed and installed.

One of the most important findings from previous DTU work is that only one air volume should be present in the solar collector loop, as otherwise fluid can be pressed up to or sucked into the collector and then freeze during cold nights. Also the very common advice to have a continuous slope in the whole collector loop was verified and with perfect mounting of straight pipes the slope can be almost zero and still drain. The required speed of the fluid to fill the system was also investigated. A speed of around 0.3-0.5 m/s gives a margin to flush the system at startup. Smaller pipes need lower speed. Also the risk of freezing during startup of cold outdoor pipes was shown to be more of an academic problem, if the pipes are not extremely long and outdoor temperatures very low. Fast filling/startup is advantageous, that also fits to quickly get siphon operation. This also reduces the pumping power. The DTU reports [1,2,3] (in Danish) contain a lot of measurable advice that can be used for advanced system design.

In this project the combination of drain back and low flow in the solar collector loop, for a solar combi system, is studied experimentally and by simulation [6]. In parallel to this project recent market investigations and experimental work has been done at Kassel University [4,5] showing that there is still a significant market and that the system operation can be made safer, more efficient and more cost effective,

with new knowledge and adapted components. Also experiences from a long period of Swedish research and development [7, 8, 9] have been integrated into the project in a second phase, when the first experimental experiences were available and small improvements were possible.

2. System design

Early laboratory investigations and experiences from low flow drain back systems at DTU [1] and [3] were used as basis for the design of the solar combi systems tested in this project. Figure 1 shows the lab solar combi system layout. Figure 2 shows the demonstration solar combi system (note the special drain back/expansion tank arrangement, to reduce heat losses and number of components). Also a special filling/draining collector loop system was built in the lab at DTU and operated for accelerated lifetime testing. This was done to see if the used evacuated tubular solar collectors would be damaged by frequent operation of the drain back principle in the long run, by for example thermal shocks. Also the durability of the solar collector during long and frequent sunny stagnation periods without pump operations was investigated in this way. Even hot starts were applied that only should occur in practice, if the control system is not properly adjusted, or out of order. Sunda Seido 5 heat pipe Evacuated Tubular Collectors are used as solar collectors.

Special fabric stratifiers are also used in the heat storages solar collector loop return inlet to the tank and as heating loop return inlet to establish thermal stratification and to minimize thermal mixing of the tank. The lab system is well instrumented for scientific level evaluation and model validation and the demo system is equipped with energy meters to get energy flows and circulated fluid volumes in the different loops.

In the lab system a traditional drain back tank is used and placed on the forward flow going down from the collector to the tank. Flexible stainless steel pipes with very large diameter (22 mm outer diameter) were also used. This created unexpected air/water pockets both indoor and outdoor that made the filling and draining less reliable due to small extra pressure drop. Also the level indicator in this system was not reliable after some time and a risk of overfilling was obvious. This is not acceptable in a commercial system as the system will most likely freeze then in winter. The collector aperture area was 6.1 m². The orientation was 15° west and with 45° tilt. The tank volume was 500 liter with a 100 liter immersed DHW tank inside. The tank was insulated with 100 mm mineral wool except for the bottom. The backup energy was supplied with an immersed direct electric heater at $\frac{3}{4}$ of the tank height.

In the demo system a combined drain back and expansion tank arrangement was tried and it has worked after some minor modifications needed, as a normal solar pump unit was used by the installer that had check valves with too high pressure drop. The check valves and pump unit are not needed in a later commercial system. In the demo system half rigid smaller diameter (12mm outer diameter) pipes were used to avoid the problem with air/water pockets. The fluid level indication for the system was made with a traditional overflow pipe that is probably safer, as an installer recognizes this from other system types. The collector aperture area was 12.2 m². The orientation was 60° west and with 27° tilt. The tank volume 750 liter with an immersed DHW tank of 150 liter. The tank was insulated with mineral wool inside a square box around the tank in a corner of the garage. The backup energy was coming from an existing district heating connection to the house. The space heating loop used floor heating. The demo system is installed in a 225 m² one family house with 3-5 inhabitants. The house was built in 2006 and has a yearly heat demand of about 20000 kWh. Heat is supplied to the house from a district heating system by means of a floor heating system.

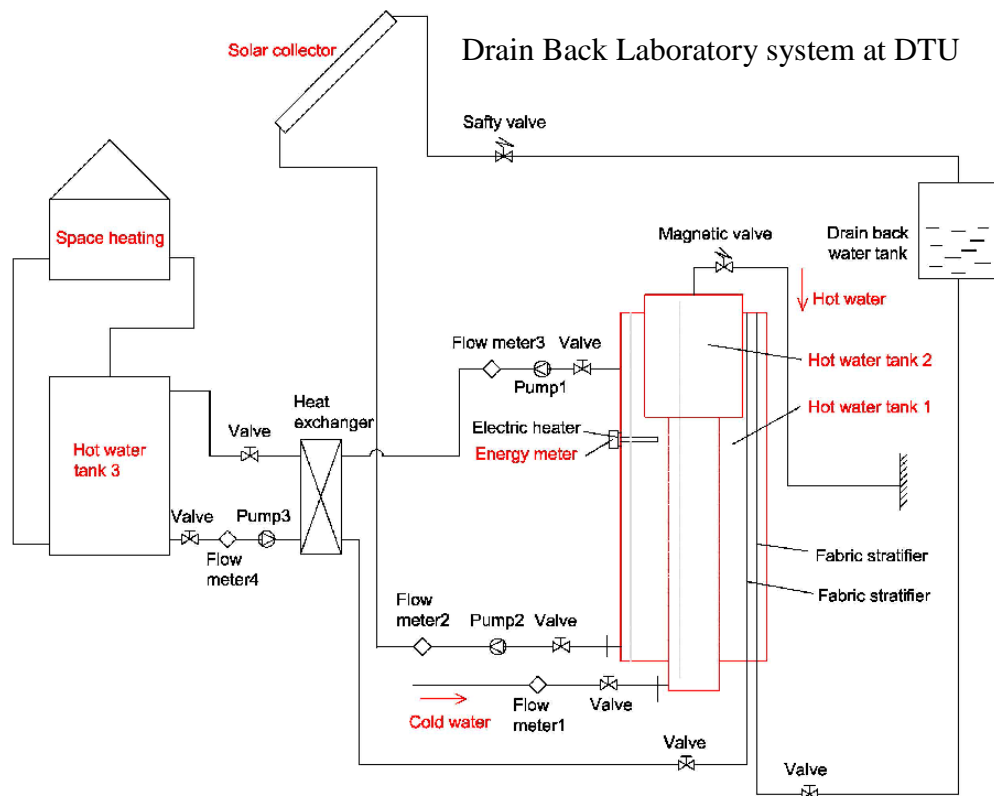


Fig. 1a: Principal drawing of the drain back low flow **laboratory solar combi system** under test at DTU.



Figure 1b. **Lab system** at DTU: Photo of the ETC solar collector in winter with snow, storage tank, controller, auxiliary heater and drain back vessel.



Figure 1c. The collector loop stainless steel flex pipes **in the lab system**, before and after slope adjustment.



Figure 2a. Sunda Seido 5, Vacuum tube solar collectors, in the **demo system**. (The PV system seen to the far left only interacts with the electric grid.)

Drain Back Demo System in Sorö

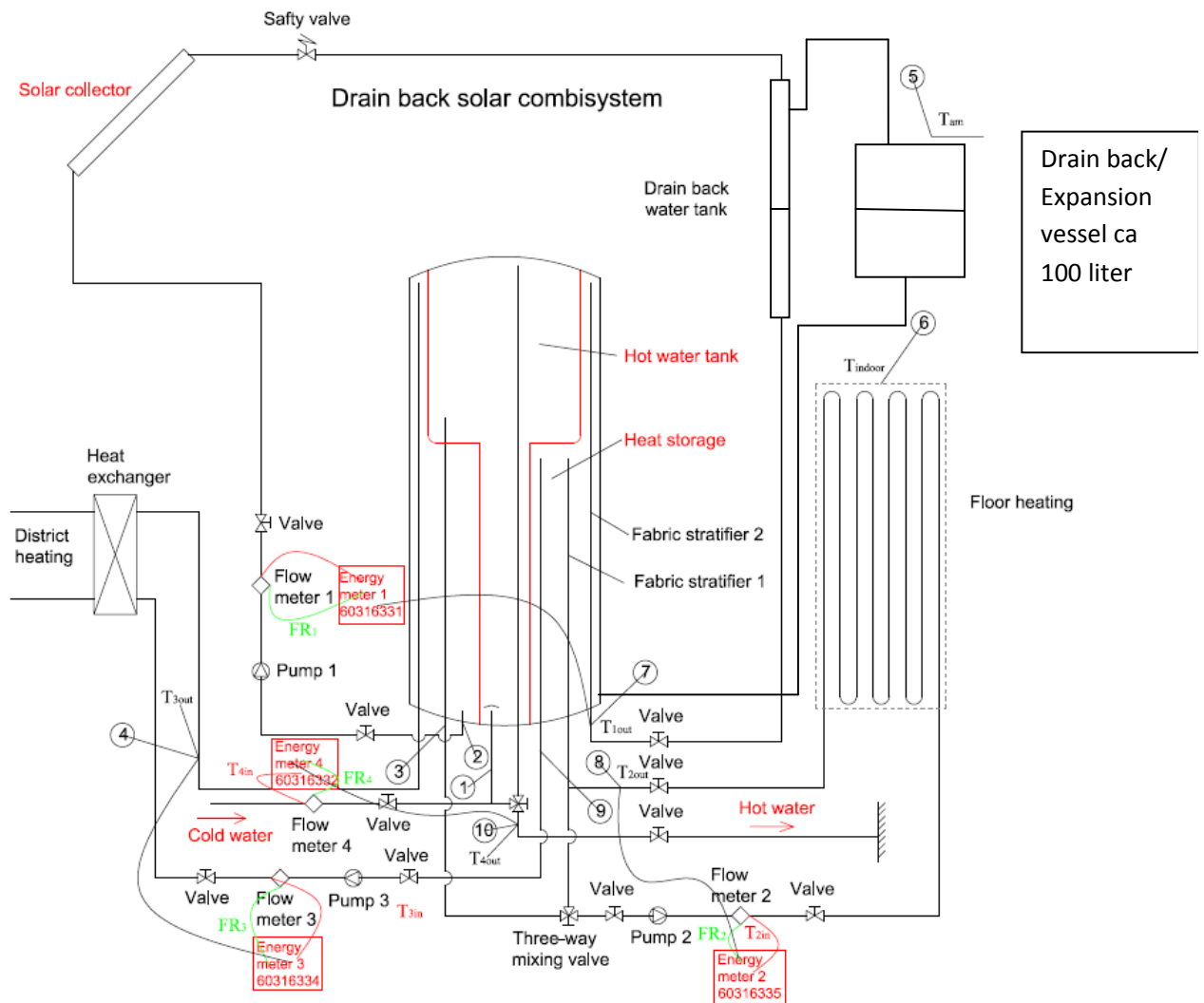


Figure 2b. **Demonstration system** inclusive energy meters in Sorö, Denmark. Note the combined drain back and expansion tank in the upper right corner of the drawing. The expansion tank is connected to the bottom of the tank, to reduce the heat losses from the tank when fluid is pressed out of the tank during heating.



Figure 2c: Some more pictures from the **demonstration system** in Sorö, Denmark. The left picture is before insulation of the storage tank. Note in the middle picture the small drain back vessels (white) and the combined expansion tank (red). Note in the right picture, the pump unit that was convenient to use for the installer, but gave extra pressure drop and malfunction of the combined expansion vessel in the beginning.

3. Experiences from Operation

The overall operational results are very positive for the drain back low flow combi systems. The main problem is to get all drain back and low flow details properly designed and installed. Also some adapted components like special drain back low flow pumps would help. The main findings from the experiments are listed below:

- Flexible stainless steel pipes in the collector loop were hanging down. This was creating small air/water pockets and freezing and unsafe draining and startup in winter. See example in fig 3.
- Too large diameter pipes for low flow in the collector loop in the lab. This prevents reliable flushing of the system at startup. Siphon draining is also less reliable and water can stay in pockets and freeze.
- Misleading/malfunctioning fluid level indicator in the drain back vessel. Very important in a commercial system that the system water level is easy to see and adjust if needed.
- Loose temperature sensor at the collector outlet.
- Air bubbles can enter the storage tank from the collector loop, due to too high flow and not enough air separation in the drain back tank. The air is collected in the top of the tank. This creates a very unsafe situation, with two air volumes, that can press fluid into the collector at night in freezing cold nights.
- Clogging of fabric stratifier from small dirt and rust particles. The tank will get less thermal stratification.
- Not intended and not necessary components were installed in the demo system, like check valves and a pump unit. This gave extra pressure drop and disturbing drain back tank safety operation.
- The steel - tank in tank design is heavier than normal and may be problematic to install without special equipment, or several persons to help.
- Manufacturing of special components and installation of test systems can take a lot of extra time.

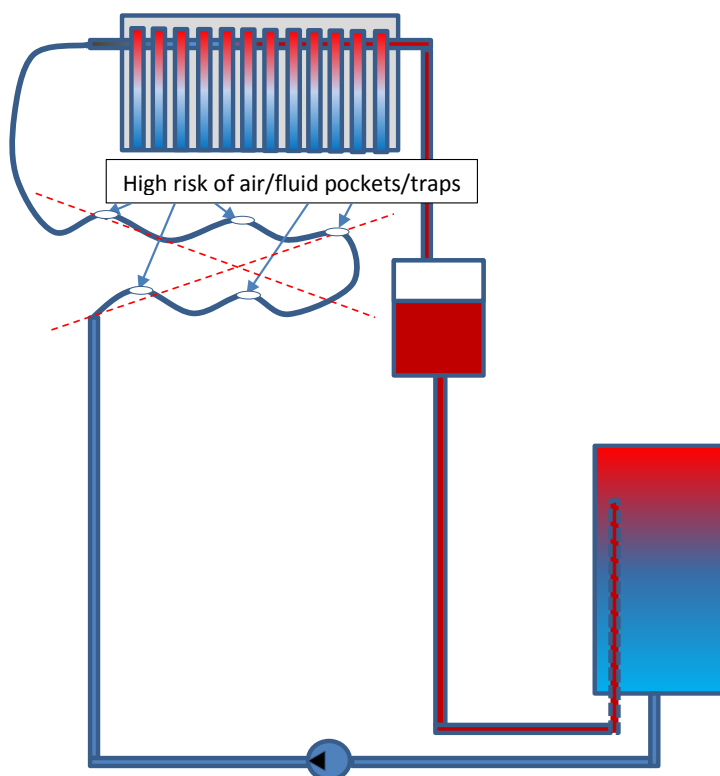


Figure 3. This picture shows a probably very common mistake to have a slight wave formed up and down slope on the collector loop pipes. This can give unpredictable air and fluid pockets/traps and extra flow resistance. This can delay or even prevent both draining and startup. This was experienced in the lab system at DTU. Only the cold side is drawn here with wrong installation, but the same problem can occur on the hot side of the collector.

4. Performance and Model Validation for the Laboratory System

The test system was operated in a bit unusual way to give as good validation data over a long period, so that many different operation conditions could be included. The domestic hot water draw off was controlled to be 100 l per day and evenly distributed at 07:00 12:00 and 19:00. This is an average Danish consumption, but can of course vary from house to house depending on number of persons and habits. The heating load was specially adapted to give a good validation data base and not according to a normal space heating profile dependent on outdoor temperature and wind for example. Therefore most of the tank energy content below the heating loop outlet was discharged by a timer every night to get a large temperature swing in the tank frequently. This gives more stress to the modelling. Also periods without auxiliary heating was applied, to get even more variability in data for model validation. This also means that long term summations of measured performance are not comparable to a normal solar combi system in a house, so this is not presented here. The idea was that after model validation the TRNSYS model could be used to simulate almost any similar drain back system design, different loads and climate situations that can be of interest to study and optimize. This later step is not done yet in the project.

A TRNSYS system layout is shown in figure 5. Note that the drain back tank is simulated as an extra pipe at the outlet of the collector, located before the tank. This simulates the extra time delay and higher heat losses due to this vessel. In the demo system this loss was minimized by combining the drain back and expansion volumes into one vessel, see figure 2b.

After collecting enough data in the lab at DTU a simulation model in TRNSYS was validated using the lab system measurements. Figure 4 shows an input output diagram [15] with TRNSYS results for a full year and measured results for a period with full experimental operation from October 2013. The diagram indicates that the TRNSYS system model can simulate the experimental system quite well.

The main deviation comes from higher heat losses for both the collector loop and the tank itself in practice, which is very common. Also the slightly malfunctioning fabric stratifier adds to the difference between measurement and simulation. This means that the collector has to operate at higher temperatures in reality than in the simulation.

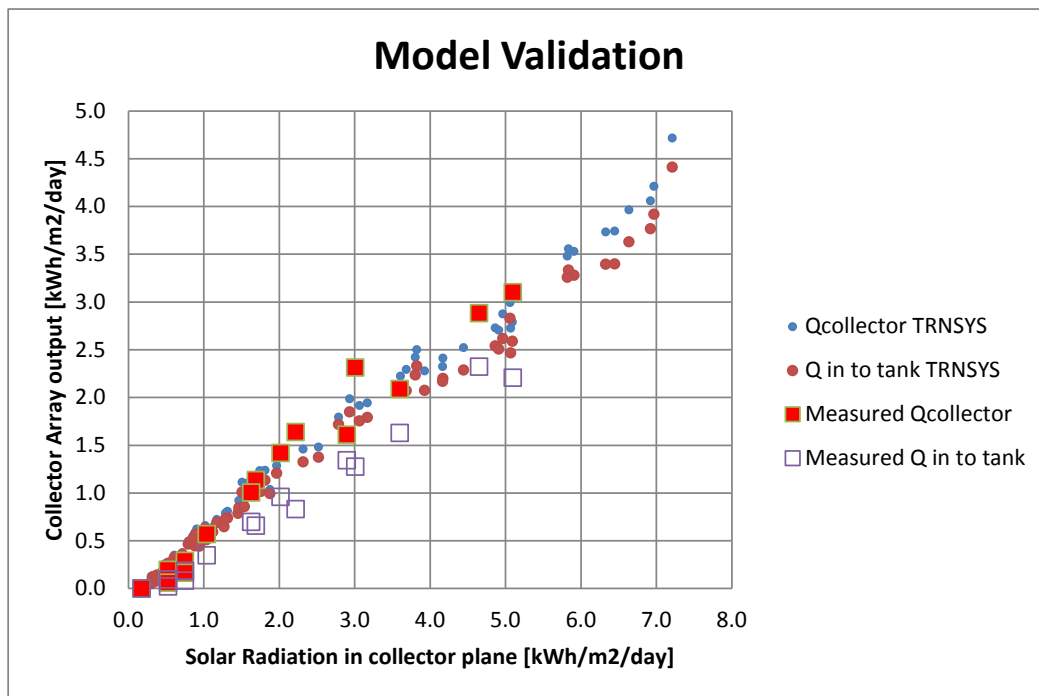


Figure 4: Input output diagram for the Lab system at DTU indicating that the TRNSYS model can simulate the experimental system quite well. The main deviation comes from higher heat losses for both the collector loop and from the tank. Also less thermal stratification in the real tank due to a clogged fabric stratifier contributes.

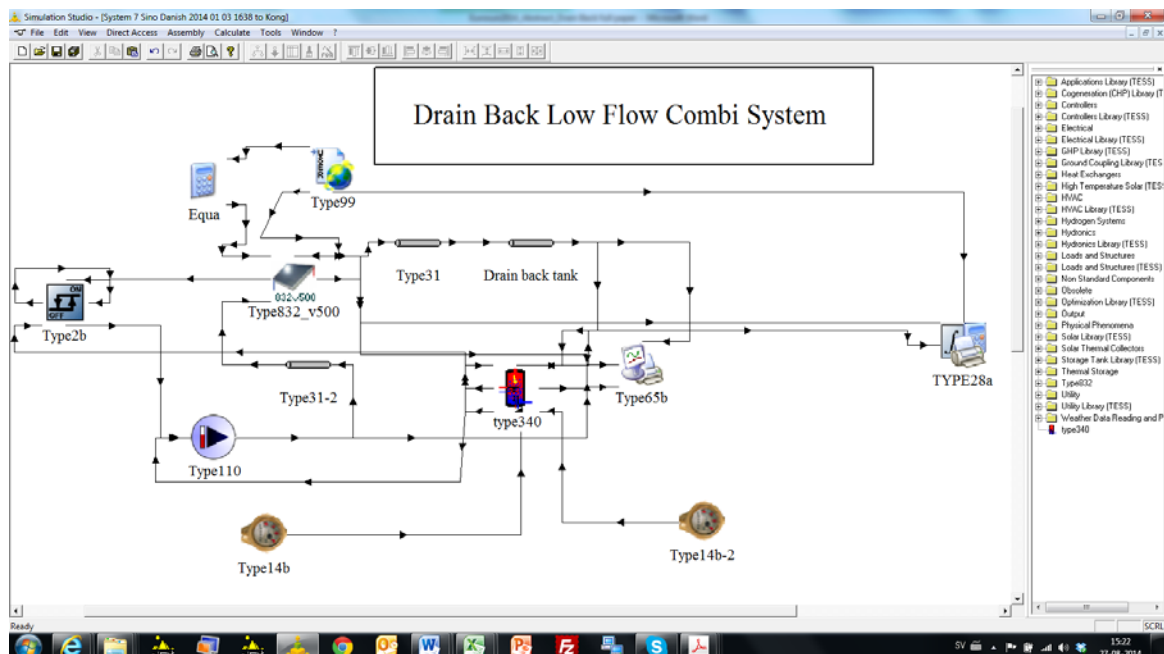


Figure 5. TRNSYS system layout. Note that the drain back tank is simulated as an extra pipe at the outlet side of the collector located before the tank. This simulates the extra time delay and heat losses due to this tank.

An overview of the TRNSYS simulation model validation results, is given in table 1 below indicating a good

match between measurements and simulation almost within the measurement uncertainty of the variables, for the two week period October 5 - October 19, 2013. The bottom line shows the ratio between TRNSYS simulation and measurement results. *It should be pointed out that the Auxiliary input, Space heating and Hot water loads, are also simulated according to controller settings and consumption patterns and not input to TRNSYS as measured values.* So it is a more complete model validation and not only of the solar part of the system.

Table 1. TRNSYS model validation results for a 2 week period for October 5-19 2013 for the lab drain back system at DTU.

| Energy Flow => | Total Solar Radiation in Coll plane | Energy from solar collector | Ecoll into tank | Espace heating | E hot water draw off | Eauxiliary to the tank | Heat loss from tank | Net Utilized Solar Energy |
|-----------------|-------------------------------------|-----------------------------|-----------------|----------------|----------------------|------------------------|---------------------|---------------------------|
| Unit => | kWh/m ² | kWh | kWh | kWh | kWh | kWh | kWh | kWh |
| Measured | 31 | 112 | 77 | 79 | 44 | 57 | 12 | 66 |
| TRNSYS | 31 | 106 | 79 | 85 | 42 | 58 | 10 | 69 |
| TRNSYS/Measured | 1.00 | 0.95 | 1.02 | 1.08 | 0.95 | 1.02 | 0.84 | 1.05 |

5. Measurements from the Demo Plant

In the demo plant only energy meters were installed to derive long term performances. Therefore no detailed information can be derived.

In figure 6 the main energy flows in the demo system are shown. The tank was not insulated in the first months. There is hot water circulation in some periods. The hot water consumption shown includes this circulation heat loss so it varies more than the hot water consumption. A point measurement indicates a huge circulation pipe heat loss of about 2.7 kW. Hot water circulation saves water and it improves the comfort very much, when hot water pipes are very long as in this case.

The net utilized solar energy, defined as domestic hot water consumption inclusive circulation pipe heat loss + space heating - heat supply from district heating, gets negative in winter when the solar contribution is very small. It is because the heat losses are not included in this definition.

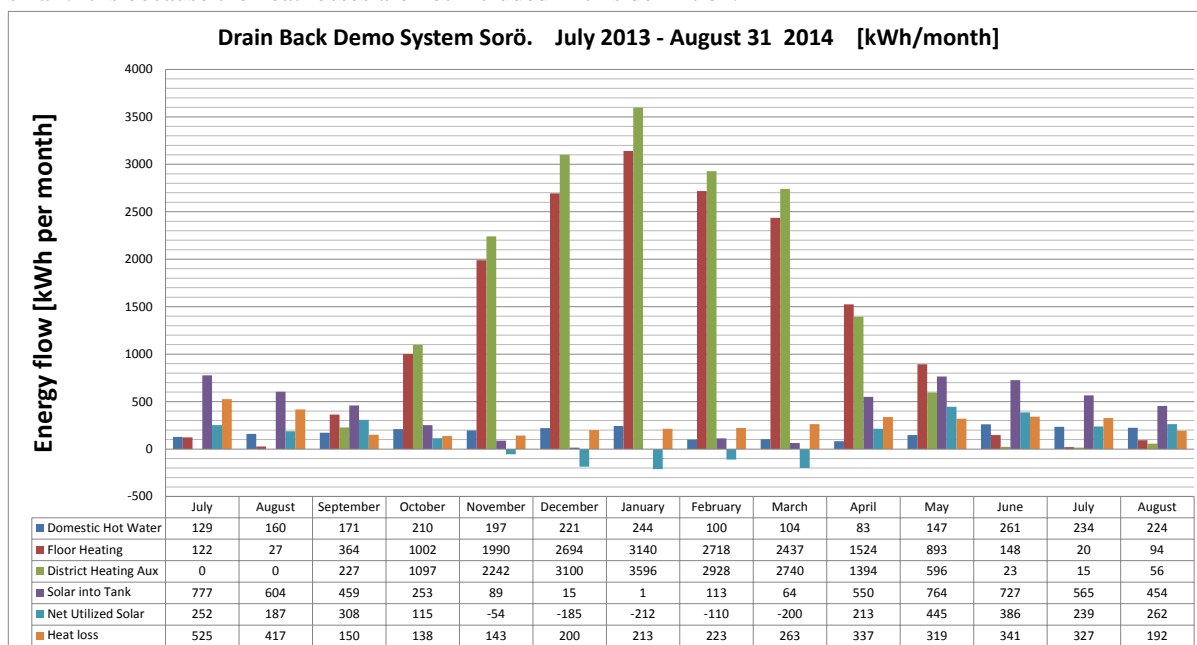


Figure 6. The main monthly energy flows and energy balance in the drain back demo system in Sorö.

As can be seen the solar combi system is oversized for the normal summer load. This is normally reduced to the domestic hot water consumption. Some comfort floor heating is used in summer as the extra solar energy use is almost free. Cold unheated ceramic or stone covered floors are avoided then. This is increasing the

comfort in summer.

An annual energy- and volume balance for September 2013 to August 2014 is given in table 2.

Table 2. Heat demands and thermal performance for one year operation.

| Hot Water | Hot Water | Floor Heating | Floor Heating | District Heating | District Heating | Collector into Tank | Collector loop | Net Utilized Solar | Heat Losses |
|-----------|----------------|---------------|----------------|------------------|------------------|---------------------|----------------|--------------------|-------------|
| kWh | m ³ | kWh | m ³ | kWh | m ³ | kWh | m ³ | kWh | kWh |
| 2196 | 115 | 17024 | 2461 | 18013 | 1053 | 4052 | 270 | 1206.5 | 2846 |

The net utilized solar energy of 1207 kWh/year, corresponding to 99 kWh/m² collector per year is only one third of the energy delivered to the tank by the solar collectors. The main difference is the tank heat losses that are not taken into account in the net utilized solar energy calculation. Part of these losses would have been covered by auxiliary energy, if not solar energy was present in the system. The tank heat losses are larger than the tap water consumption including circulation pipe heat loss in this case. This is due to the less well insulated storage tank. Also some shorter connecting pipes were still uninsulated and add up to the relatively large heat losses.

The solar energy into the tank corresponds to 332 kWh per m² collector. The collectors have too little load during summer and operate at very high temperatures then, so the output is reduced. The collectors can of course not produce more than the load plus tank heat losses.

6. Conclusions and Recommendations

After some minor initial installation problems and redesign, mentioned above, the systems have been in continuous operation with only minor problems. The operating problems were mostly on the monitoring side as it is long term measurements and sensors and data loggers can fail after some time.

- 1) Continuous slope of pipes above the drain back level is very essential. The use of stainless steel flexible pipes in the collector loop should be avoided, unless mounted very carefully to avoid water pockets.
- 2) Only one, closed air volume should exist in the system, to make the drain back function 100% reliable and to avoid oxygen coming in and thereby avoid corrosion inside the system.
- 3) The combination of a drain back vessel (pipe in this case) and system expansion tank, can be a good solution, see fig 2. In an extreme design the drain back vessel can be integrated into the top of the tank. This combined tank should be connected to the bottom of the storage tank to avoid extra heat losses.
- 4) It is possible to avoid all heat exchangers in the system and use the same fluid (water) everywhere, except for domestic hot water. For domestic hot water, a tank in tank system solution is recommended, see fig 1b and 2b.
- 5) A standard pump can be used in the collector loop, if the drain back tank is placed high enough, but still indoors.
- 6) An adapted control system is desirable, that can increase the flow in the collector loop during startup and thereby flush it, so that the pumping power can go down by siphon action in the forward pipe down to the tank or drain back vessel. Also blocking of start at extremely cold outdoor temperatures could be one feature if long outdoor pipes are needed in the collector loop.
- 7) The mounting of the collector temperature sensor is important to have good thermal contact to the collector outlet temperature during startup and the outlet fluid during operation, but at the same time avoid overheating of the sensor during stagnation.
- 8) Installer education and training is very important (like for normal glycol systems.)
- 9) A TRNSYS model has been developed for the system type and validated with reasonable accuracy against measured data.

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